UTE OF TECHNOLOGY
AUTICAL LABORATORY
HYPERSONIC WIND TUNNEL
Pasadena, California

MEMORANDUM NO. 29

July 31, 1955

INSTRUMENTATION OF GALCIT HYPERSONIC WIND TUNNELS

by
Paul E. Baloga
Henry T. Nagamatsu

SPONSORED BY ARMY ORDNANCE AND AIR FORCE
CONTRACT NO. DA-04-495-Ord-19

Contract No. DA-04-495-Ord-19

Army Ordnance Department

Sponsored by Army Ordnance and Air Force

MEMORANDUM NO. 29

INSTRUMENTATION OF GALCIT HYPERSONIC WIND TUNNELS

Paul E. Baloga

Henry T. Nagamatsu

Henry T. Nagamatsu, Director
Hypersonic Wind Tunnel

Clark B. Millikan, Director
Guggenheim Aeronautical Laboratory

Copy No. ____

GUGGENHEIM AERONAUTICAL LABORATORY
California Institute of Technology
Pasadena, California

July 31, 1955

TABLE OF CONTENTS

I. INTRODUCTION

For the purpose of developing more efficient rockets and missiles for long ranges, it is necessary to acquire basic information in the hypersonic Mach number range of 5 to 20. To obtain such aerodynamic information two Hypersonic Wind Tunnels, Legs No. 1 and No. 2, have been developed at GALCIT. With Leg No. 2 it is possible to obtain aerodynamic information in one-phase air flow at a Mach number of about 11.

During the early operation of the Leg No. 1 tunnel at a Mach number range of 2 to 7 it was necessary to develop various new experimental techniques to obtain reliable aerodynamic information. The static pressures in the test section varied in the hypersonic Mach number range from about 2 to 1/4 millimeters of mercury while the static temperature was of the order of room temperature to 1100°F. A great deal of time was spent in developing manometer boards and special valves and in perfecting new techniques for measuring these low pressures very accurately. The initial operation phase of the Leg No. 1 tunnel was spent in developing adequate hypersonic instrumentation for static pressure, total head, heating facilities, and a stagnation temperature controller.

In this report the important instrumentation developed over the past few years will be discussed in detail. The information should be useful for other groups planning basic research at hypersonic Mach numbers.

II. HYPERSONIC WIND TUNNEL DESCRIPTION

The two GALCIT 5" x 5" Hypersonic Wind Tunnels are of the closed return, continuously-operating type and are operated alternately by a compressor plant consisting of sixteen compressors arranged in a parallel-series circuit. A schematic diagram of the wind tunnel installation is shown in Fig. 1A, and the control panel is shown in Fig. 1B.

In operating these two tunnels, use is made of a variety of instrument devices, some for proper control of the compressor plant and others for obtaining wind tunnel data under properly-controlled pressures and temperatures. In this memorandum is presented a brief description of the instruments used at this laboratory. Several of these have been designed and built at the laboratory while others are purchased items which have been modified for special applications.

The use of a single compressor plant for two wind tunnels has a decided advantage over conventional methods since it decreases the shutdown time of the compressor plant to a minimum. A portion of this shutdown time is used for maintenance and repair. During the time when one tunnel is operating, the other, together with its associated instrumentation, is free for model installation.

The two wind tunnels are referred to as Leg No. 1 and Leg No. 2, respectively. The pertinent characteristics and specifications unique to each are described as follows:

A. Leg No. 1, Mach Number Range 2-7

Leg No. 1, which is now operating with the nozzle blocks set for Mach 5.8, is designed for a maximum stagnation pressure of 1040 psi. The air is heated to a maximum of 400°F during its passage through a steam heat exchanger directly after its exit from the last stage of compression.

B. Leg No. 2, Mach Number Range 4-11

Leg No. 2, which can be operated up to Mach 11, has a maximum stagnation pressure of 1040 psi. The air is heated electrically to a maximum of 1100°F in the stainless steel settling chamber just ahead of the throat. Semi-flexible nozzle plates designed to operate over a Mach number range of 7 to 11 have been installed, and the nozzle is being calibrated at the present time.

III. COMPRESSOR PLANT INSTRUMENTATION

A. Variable Conditions Indicated on the Control Panel

1. Inlet and Outlet Pressures for Each Stage of Compression

These pressures are measured with standard bourdon tube pressure gages.

2. Outlet Air Temperature for Each Stage

The outlet air temperature is measured with standard iron constantan thermocouples and recorded with a multi-point strip-chart recorder.

3. Compression Ratio of Certain Compressor Stages

This ratio is of interest only when it approaches the design limit which is specified by the compressor manufacturer. The critical compression ratio is indicated on a duplex gage of a certain design. These gages have two bourdon movements in one housing with their pointer shafts concentric. The movements are so chosen that the ratio of their sensitivities is equal to the critical compression ratio of the compressor under consideration. With this arrangement the inlet pressure-pointer leads the outlet pressure-pointer when the compression ratio is less than critical. When the two pointers coincide, the limit has been reached. This "ratio gage" then permits the plant operator to determine immediately the margin of safety for that particular stage.

4. Stagnation Pressure

This pressure is measured with a Tate-Emery indicator which can measure up to 1300 psi in four ranges (described separately).

5. Stagnation Temperature

Stagnation temperature is measured just ahead of the throat with iron-constantan probes feeding into a continuously-recording controller.

B. Description of Measuring and Controlling Instruments and Techniques

1. Operation of Tate-Emery Pressure Indicator

The multiple-range Tate-Emery is shown schematically in Fig. 2. The operation is as follows:

Carefully regulated nitrogen (25 psi) is brought into the bellows, extending them against the action of the tension springs (S). Air pressure (P_o) entering bourdon tube (A) deflects it together with the attached flapper (B) in the direction shown. This changes the leakage rate from orifice (C) causing the bellows (D) to collapse because of decreased pressure. Spring (E) is a negative position feedback from the bellows to the bourdon tube flapper combination. The flapper finally assumes some equilibrium position, giving a unique leak rate and a unique position of the bellows for each pressure (P_0). The deformed status of the bellows is transmitted through the rack and pinion (F and G), thus giving a unique position of pointer (H) on the indicator dial.

Bottled nitrogen is used to operate this indicator, thus eliminating the need for attention to filtering and drying devices, which would be necessary if the available "house" compressed air were to be used.

2. Method of Stagnation Pressure Control

Constant stagnation pressure, which is necessary for proper wind tunnel operation, is held by means of a differential pressure controller of the type used in the process industries for flow control. It is used in the following manner (Fig. 3):

Air is permitted to enter a pressure bottle until it is charged to a pressure equal to the pressure at which the tunnel is to be operated. At this time a hand valve (V_1) is closed, isolating this pressure, which has been measured with the Tate-Emery indicator and which is to be used as the reference pressure on one side of the controller bellows. The air pressure to be controlled is brought to the other side of the bellows and is compared against the reference pressure. When there is a pressure difference, the controller actuates a diaphragm-operated valve, venting more or less air to atmosphere from the system in order to equalize the pressure in the bellows. Pressures to within .04 psi are easily held.

3. Air Temperature Control

a. Control for Leg No. 1 Steam Heat Exchanger

The air, which has been dried with silica gel and filtered through a series of filters consisting of activated charcoal, sintered carbon, and a special glass filter cloth during its passage through the compressor plant, is then passed through the steam heat exchanger. Just before its entrance into the exchanger, a portion of the relatively-cool air is bled off through a pneumatically-operated valve. This diverted air is then used for finer temperature control by mixing it with the heated air on the exit side of the heat exchanger.

The temperature of the final air is controlled by means of a pneumatic controller incorporating both derivative and integral modes. The pneumatic pressure signal from this controller is a function of the heat input necessary to keep the stagnation temperature at a pre-set value.

The diaphragm valve (Fig. 4), which is actuated with air pressure from the controller and which controls the steam flow into the heat exchanger, is connected in such a way as to be closed with no air pressure on its diaphragm while the valve controlling the cool and heated air mixture ratio is normally open with no air pressure on its diaphragm. This mixing valve is also operated by the same pressure signal which operates the steam valve. In this way they operate in opposite sense, which diminishes the time constant of the cooling portion of the control cycle. This feature is of considerable importance due to the large thermal capacity of the steam heat exchanger.

b. Control for Leg No. 2 Heaters

The compressor plant which is used for the Leg No. 1 tunnel is also used, together with its associated drying and filtering equipment, for operating the Leg No. 2 tunnel. The air in Leg No. 2, however, is electrically heated in the stainless steel pressure vessel just ahead of the nozzle. The same temperature recorder-controller as is used in Leg No. 1 is used to control the temperature in Leg No. 2. This controller uses standard thermocouple input, giving a pneumatic signal in the form of varying pressure as the control output. This varying pressure from the controller is transformed into an electrical equivalent signal by means of a GALCIT-designed transducer (Fig. 5). The transducer consists of a diaphragm motor actuating, through a rack and pinion, a variable resistor, which in turn is used to control a saturable reactor.

Stagnation temperatures in Leg No. 2 have been controlled up to $900^{\circ}F \pm 1^{\circ}F$, with the use of this controlling technique.

IV. PRESSURE MEASURING METHODS

A. Low Pressure Silicone Manometer Banks

Most of the pertinent pressures in the wind tunnel test section are measured with 100 cm full scale silicone manometer banks designed and built at this laboratory. In Fig. 6 the schematic arrangement of the reservoir and valving is shown, and Fig. 7 shows the manometer board.

This is a standard reservoir type manometer using the GALCIT-design, three-way vacuum valve (Fig. 8). When no pressure readings are being taken, the valve is in such a position as to expose the liquid column to the same low pressure as the reservoir. This reservoir pressure is kept at between 3 and 10 microns of mercury pressure and is checked regularly by means of an ionization pressure gage called the "Alphatron". This keeps the silicone fluid under continuous vacuum, which is necessary in order to prevent air from becoming dissolved into the liquid. When pressure readings are to be taken, the valve is adjusted to the position shown in the figure, which exposes the liquid column to the pressure being measured (Fig. 6).

The silicone liquid used in the manometers is known commercially as Dow Corning Compound 200. For this application a viscosity rating of 10 centistokes is used.

B. Low Pressure Micromanometer Bank

A twelve-tube micromanometer bank has been designed and built for pressure readings which require accuracies greater than .2 mm of silicone (Fig. 9). This micromanometer is capable of sensitivity in the order of .005 mm of silicone. This sensitivity is attained by projecting an image of the meniscus in the glass tube onto a ground glass viewing screen, on which there is scribed a horizontal index line. The meniscus and the index line are superimposed by adjusting the elevation of the projection system by means of a motor-drived precision lead screw. This elevation is then read from the counter, which is geared to the lead screw to read directly in increments of .01 mm. The full range of the micromanometer is 30 cm.

In order to improve visibility the silicone fluid is dyed a blue color by passing it through filter paper on which is sprinkled dye (Calco oil blue, ZA ex conc. from the American Cyanamide Co., Calco Chemical Division, Dyestuff Department, Boundbrook, New Jersey).

C. Tilting "U" Tube Micromanometer

A micromanometer with a range of one inch has been developed. This unit can use either silicone or mercury with a sensitivity of $\pm$ .0005 in. (Fig. 10). It is essentially a "U" tube with short legs, which can be tilted about the pivot (P) by means of a machinist's micrometer head (M). The manner of operation is as follows:

Stopcock (S) is turned to the position which exposes both liquid columns to the reference pressure. At this time the micrometer is adjusted to the "null" position, which is indicated at the surface of the fluid by a distortion of the reflected light (L). This distortion is caused when the point of the "catwhisker" pierces the meniscus of the manometer fluid. This "piercing point" is quite definite and can be repeated to within .0005 inch. This "null" position of the micrometer is recorded as the reference level. The stopcock is then turned to the alternate position which exposes the liquid columns to the reference and the unknown pressure, respectively. The micrometer is again adjusted for the new null. The difference in micrometer readings gives the head (h) of manometer liquid. (.0005 in. of silicone is equivalent to .8 microns of mercury.)

V. MISCELLANEOUS

A. Carbon Dioxide Concentration Meter

Since carbon dioxide acts as a nucleant for air condensation when it is present in quantities greater than a certain critical amount[1], it is of interest to monitor the CO_2 concentration, particularly in Leg No. 2, where it could possibly build up due to the burning of small oil particles as they pass through the electrical heater while being carried through the air stream from the compressor plant. With this in mind a continuously-sampling analyzer was designed and built. (Fig. 11)

Operation of this analyzer is based on the fact that the quantity of carbon dioxide dissolved in water is proportional to its partial pressure in the gas mixture to be analyzed.

$$CO_2 = \frac{\alpha}{22.4} = p\,CO_2$$

where

CO_2 = concentration of dissolved carbon dioxide

$p\,CO_2$ = partial pressure of carbon dioxide in atmosphere

Carbon dioxide - bicarbonate equilibrium reaction:

$$CO_2 + H_2O \rightleftharpoons HCO_3^- + H^+$$

To measure the hydrogen ion (ph) concentration an indicator is used in the solution, in this case bromo-thymol blue. The color range of this indicator is from yellow on the acidic side to deep blue on the

---

1. "Effects of Impurities on the Supersaturation of Nitrogen in a Hypersonic Nozzle", by P. D. Arthur and H. T. Nagamatsu, GALCIT Hypersonic Wind Tunnel Memorandum No. 7, March 1, 1952.

basic. The ph of the indicating solution is adjusted, before measurements are taken, to fall somewhere between the two extremes, that is, when the bromo-thymol blue appears greenish. The adjusting solutions used are very dilute solutions of hydrochloric acid and sodium hydroxide and are made while either the standard air or sample air is bubbled through the solution.

When equilibrium has been reached, an approximately equal amount is poured into the bubbling cells, in this case consisting of two pyrex test tubes.

The determination is made as follows: With Valve 3 opened to permit the standard air to bubble through one of the cells and Valve 2 opened to bubble the sample air through the other cell, an observation is made of the colors of the solution. With sample air containing a greater percentage of CO_2 than the standard air, there will be brought about a color mismatch. Valve 1 is then adjusted until the sample air is properly diluted to bring about a color balance. From the calibrated flowmeters a ratio of dilution can be secured. With this ratio and the known concentration of carbon dioxide in the standard air, the concentration in the sample air can be computed.

The standard air can be made up for special concentrations, or ordinary outdoor atmospheric air can be used for measuring in the range of .03% concentration of CO_2. Many investigators have found outdoor atmospheric air to contain between .031 and .032% carbon dioxide, this figure being constant over various parts of the country.

It has not been difficult to sense 70 parts per million of CO_2 with visual color comparison in the test tube cells. This represents approximately .1 ph change. Obviously, when more sensitivity is required, other methods of ph measurement are required, that is, precision optical and photoelectric colormeters and electronic ph meters.

B. Schlieren Optical System

The schlieren system is a conventional "Z" configuration with traversing flats which can be controlled from the camera sight. (Fig. 12). This permits rapid monitoring of the complete length of the test section through a series of glass ports which are spaced at regular intervals on the sidewalls.

The pertinent specifications of the schlieren system are as follows:

Spherical Mirrors

f.l. 120 inches
surface $\pm$ 1/4 λ
dia. 8 inches

Flats

surface $\pm$ 1/4 λ
dia. 12 inches

Lamp

General Electric BH-6
high pressure mercury vapor
air cooled

Slit Size

1 mm x 5 mm (nominal)

Film Size

4" x 5"

Shutter Speed Range Available

1/400 sec........ 1 sec.

C. High Pressure Dew Point Indicator

The dew point indicator shown in Fig. 13 has been designed for measuring the dew point of air at pressures up to 1000 psi. It is of conventional design using the cooling effect of carbon dioxide which is expanded against the rear of a chromium-plated mirror. The temperature of this button is read at the time that dew deposit is observed through the window. With the temperature and pressure known, the specific humidity can be computed or read directly off the chart (Fig. 14).

D. Oil Removal

During the normal operation of the compressor plant which is used for operating the two wind tunnels, oil of the order of 1 quart per hour is added to the air stream. Removal of this large amount of oil is accomplished by a series of different types of filters.

After each compressor there is a vortex type of filter, commonly called a cyclone separator, which removes the largest part of the oil. Next, all of the air passes through an impingement filter made up of canisters filled with absorptive, activated charcoal (cocoanut shell), which also removes oil vapors. It is believed that the oil at this point is in the form of droplets, and the air is passed through two different porosities of sintered carbon blocks* 1" thick, which take out drops over 10 microns in diameter.

The final stage of filtering is done by a commerically-manufactured fiberglass paper manufactured by the Mine Safety Appliances Company.**

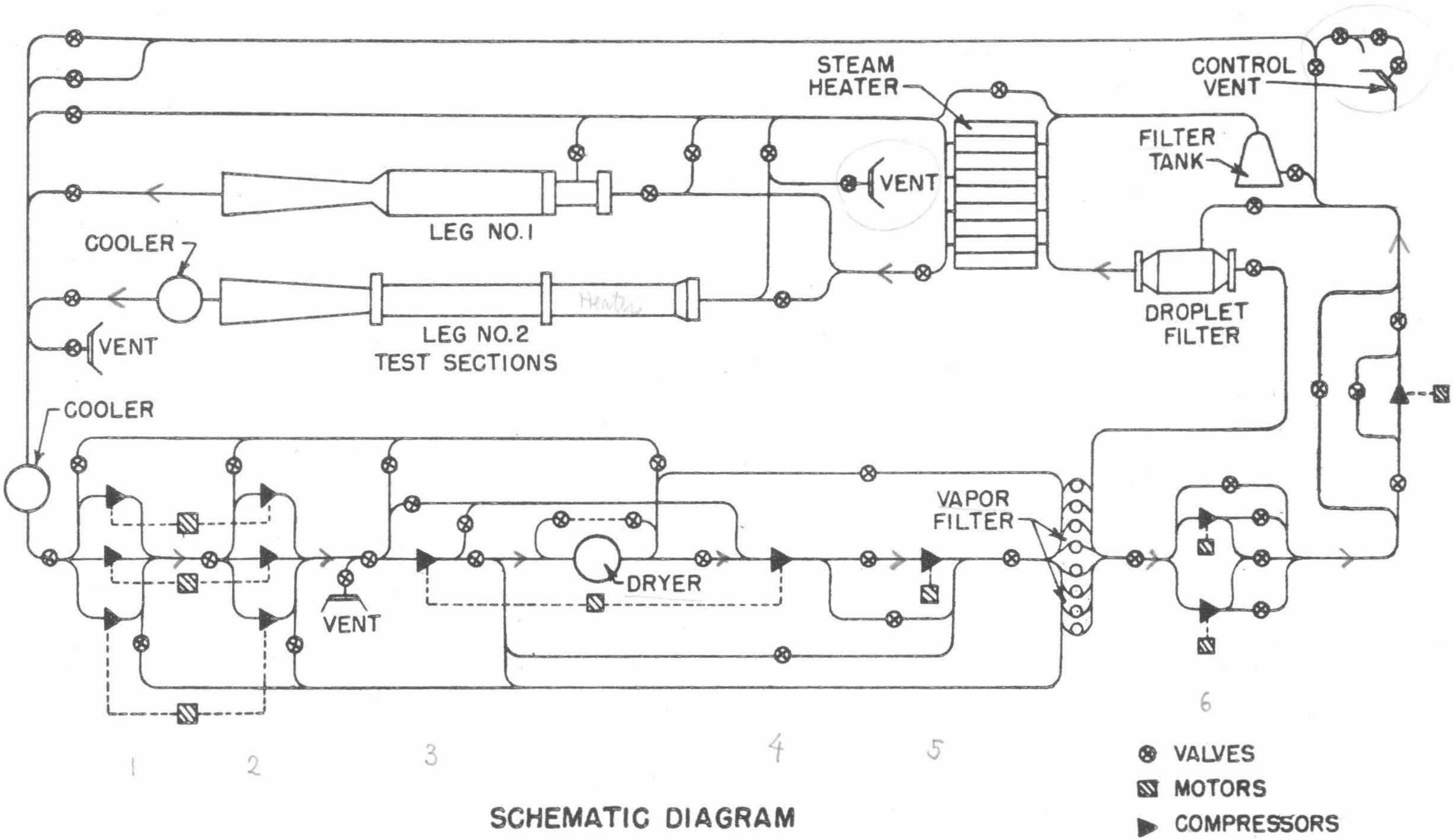
---

* National Carbon Company, 30 East 42nd Street, New York 17, N. Y.

** Mine Safety Appliances Company, Braddock, Thomas, and Meade Streets, Pittsburgh 8, Pennsylvania.

The M. S. A. filter, called "Ultra-Air Space Filter", comes as a unit ready for installation. This filter is unconditionally guaranteed to be 99.95% effective against particles .3 micron in diameter with a pressure drop of 1 inch of water. It has been in use at this laboratory for one year, passing 60 pounds of air per minute at a velocity of 55 ft. per minute and has required only three washings to date. These washings, using carbon tetrachloride, were done when a pressure drop of two inches of water was indicated across the filter.

Internal Mem. about compressor



SCHEMATIC DIAGRAM

OF GALCIT 5x5in. HYPERSONIC WIND TUNNEL INSTALLATION

FIG. 1A

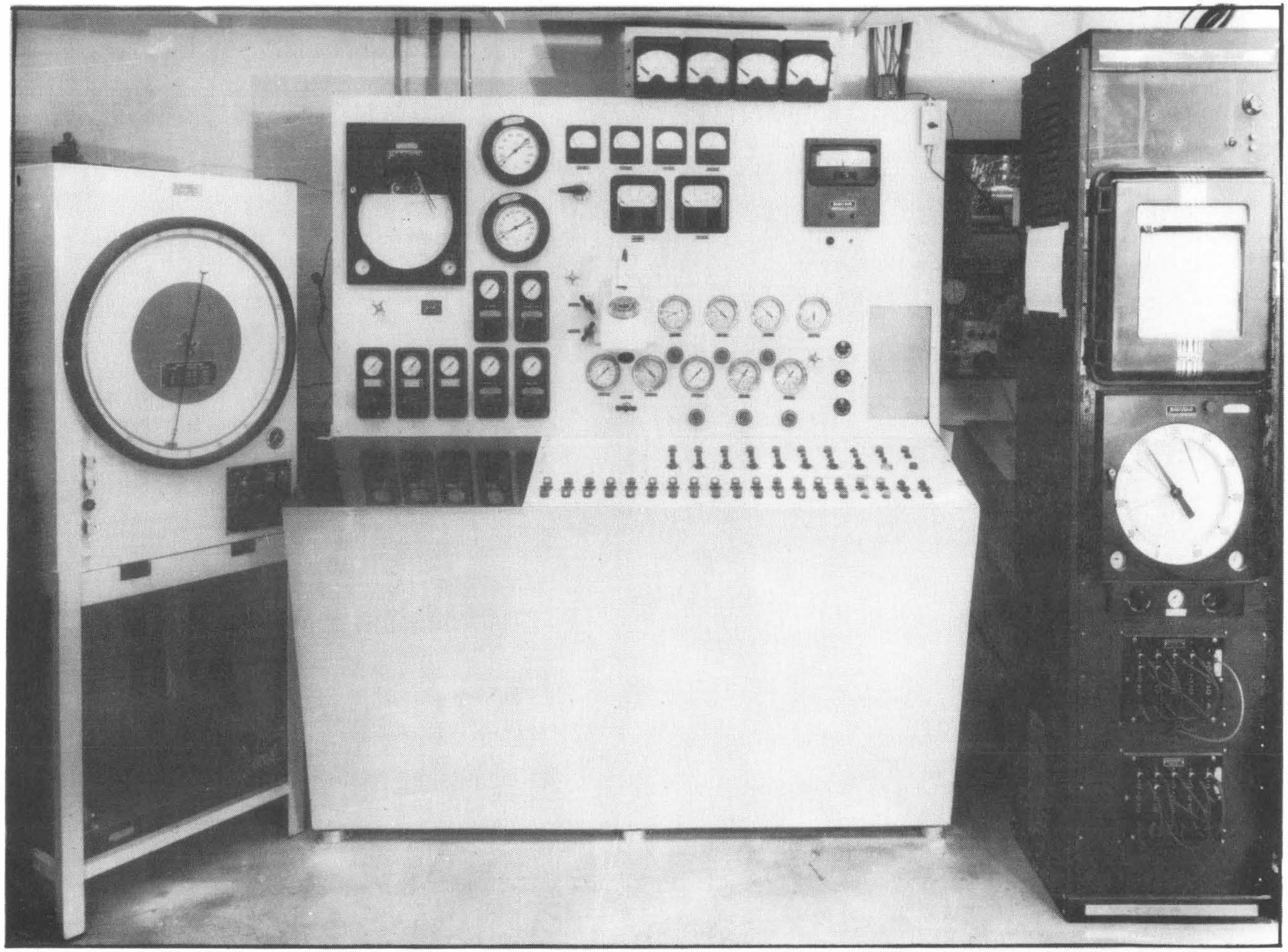
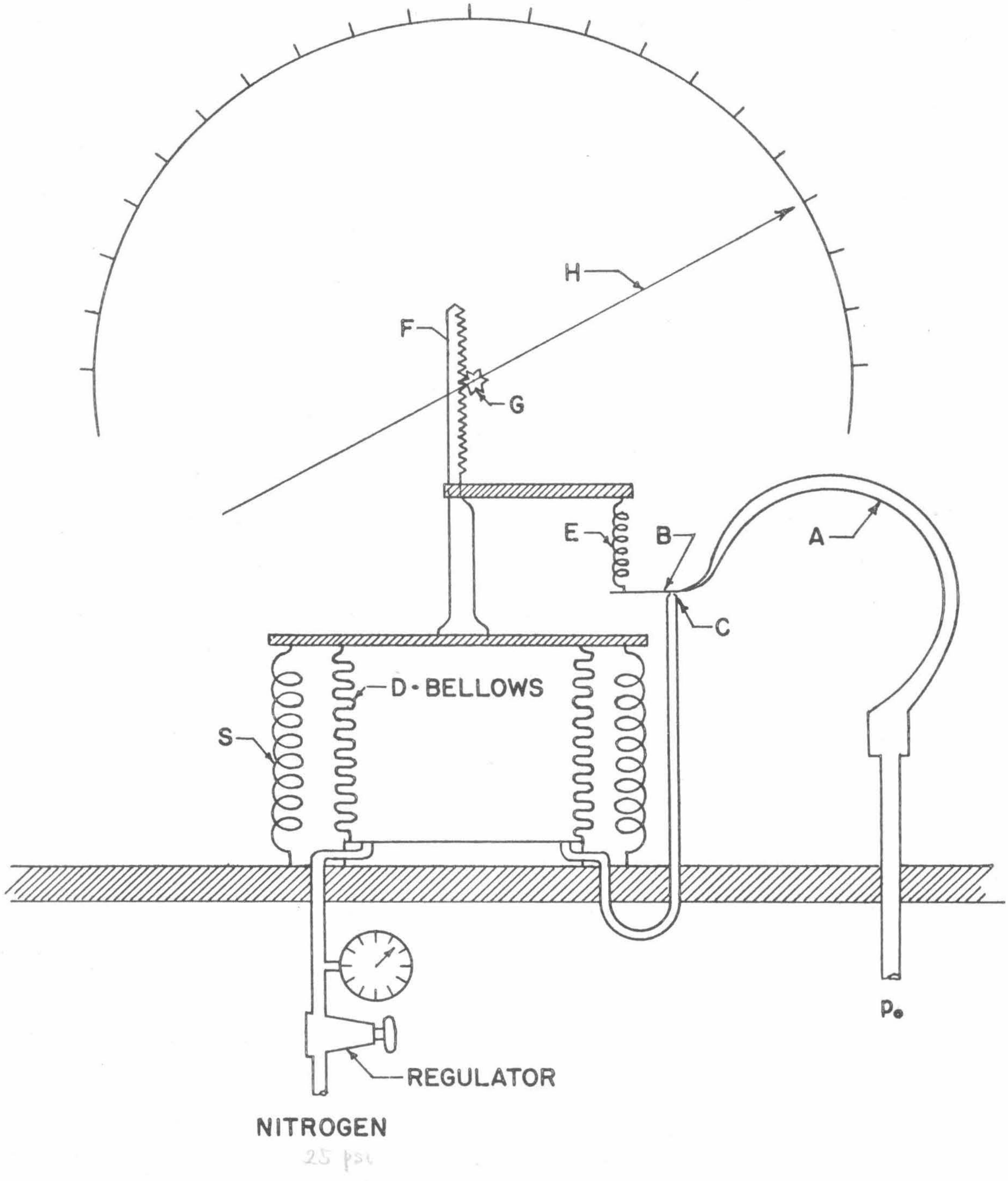


FIG. 1B

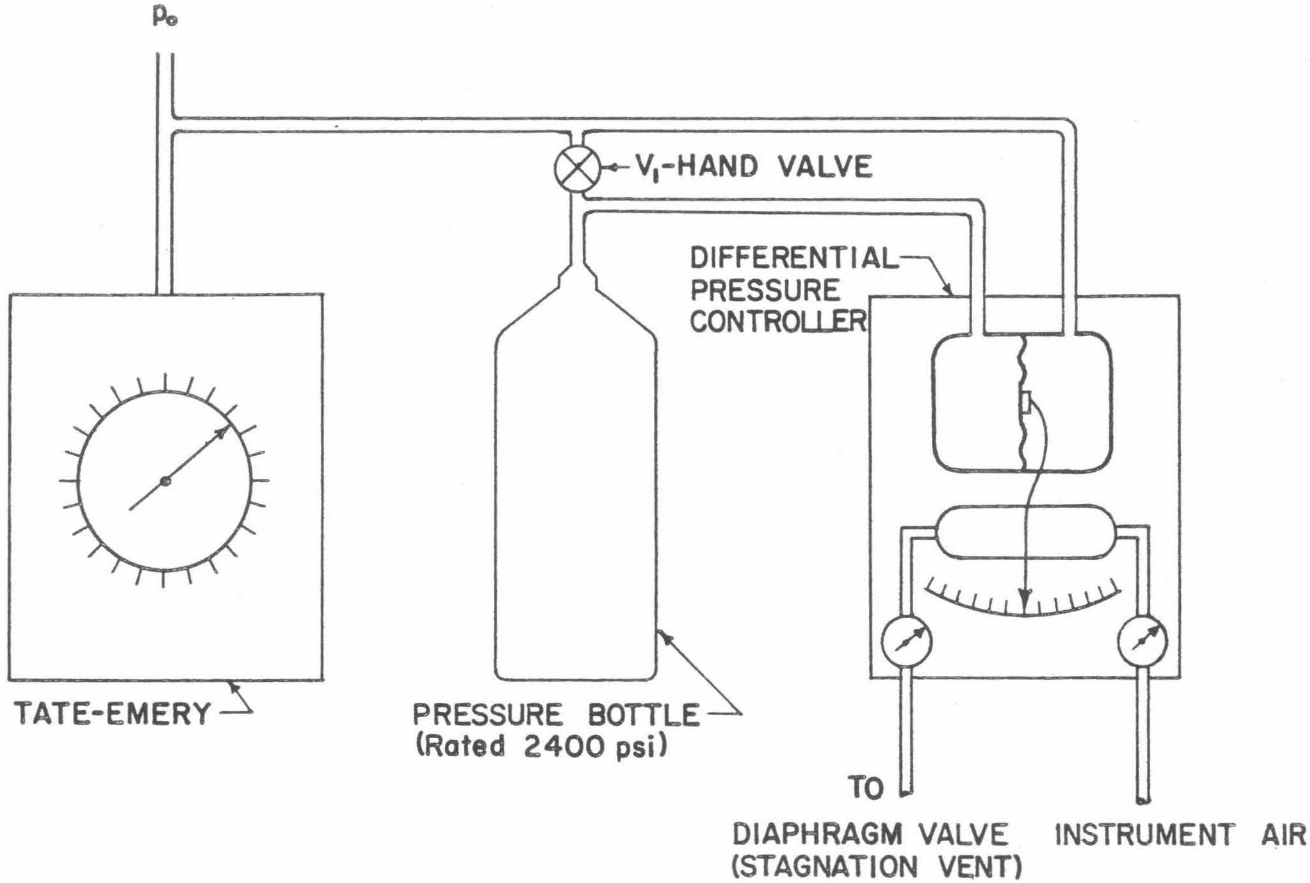
PLANT CONTROL CONSOLE, TEMPERATURE AND PRESSURE INDICATORS AND CONTROLLERS

Hesse Bourdon Tube Co.
Brook Road, Newtown, Connecticut.



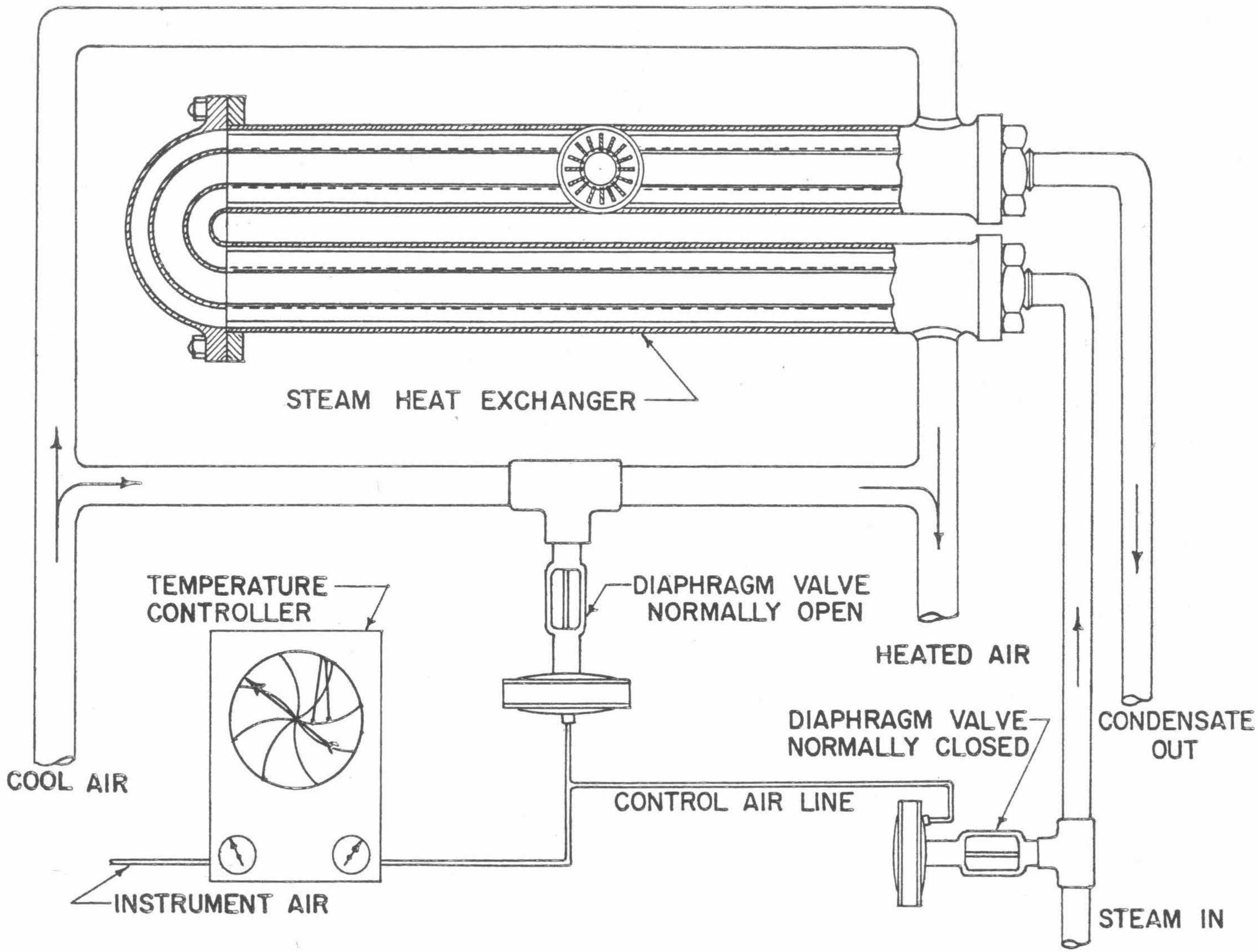
SCHEMATIC OF TATE-EMERY PRESSURE INDICATOR

FIG. 2



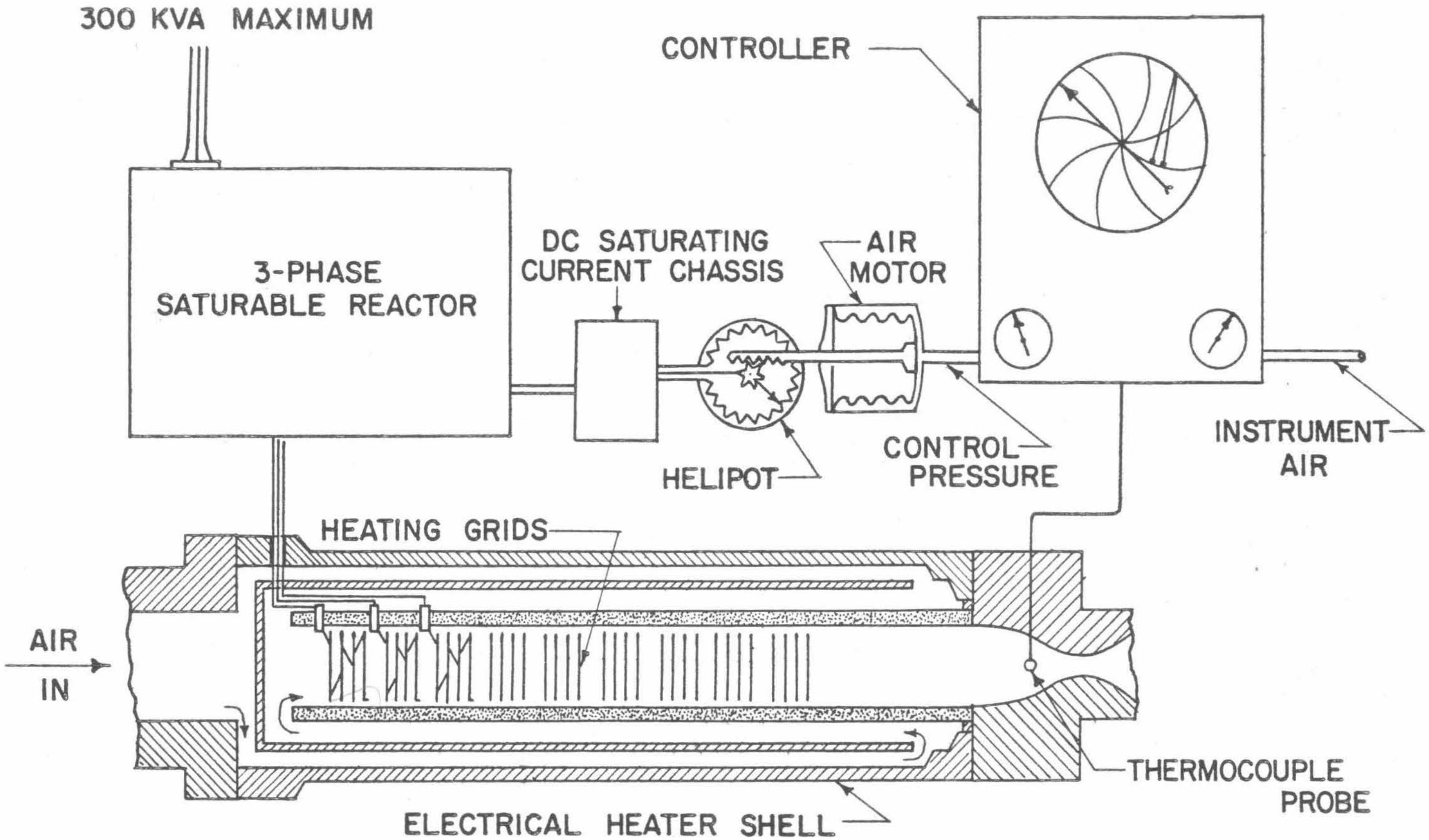
SCHEMATIC OF STAGNATION PRESSURE CONTROL METHOD

FIG. 3



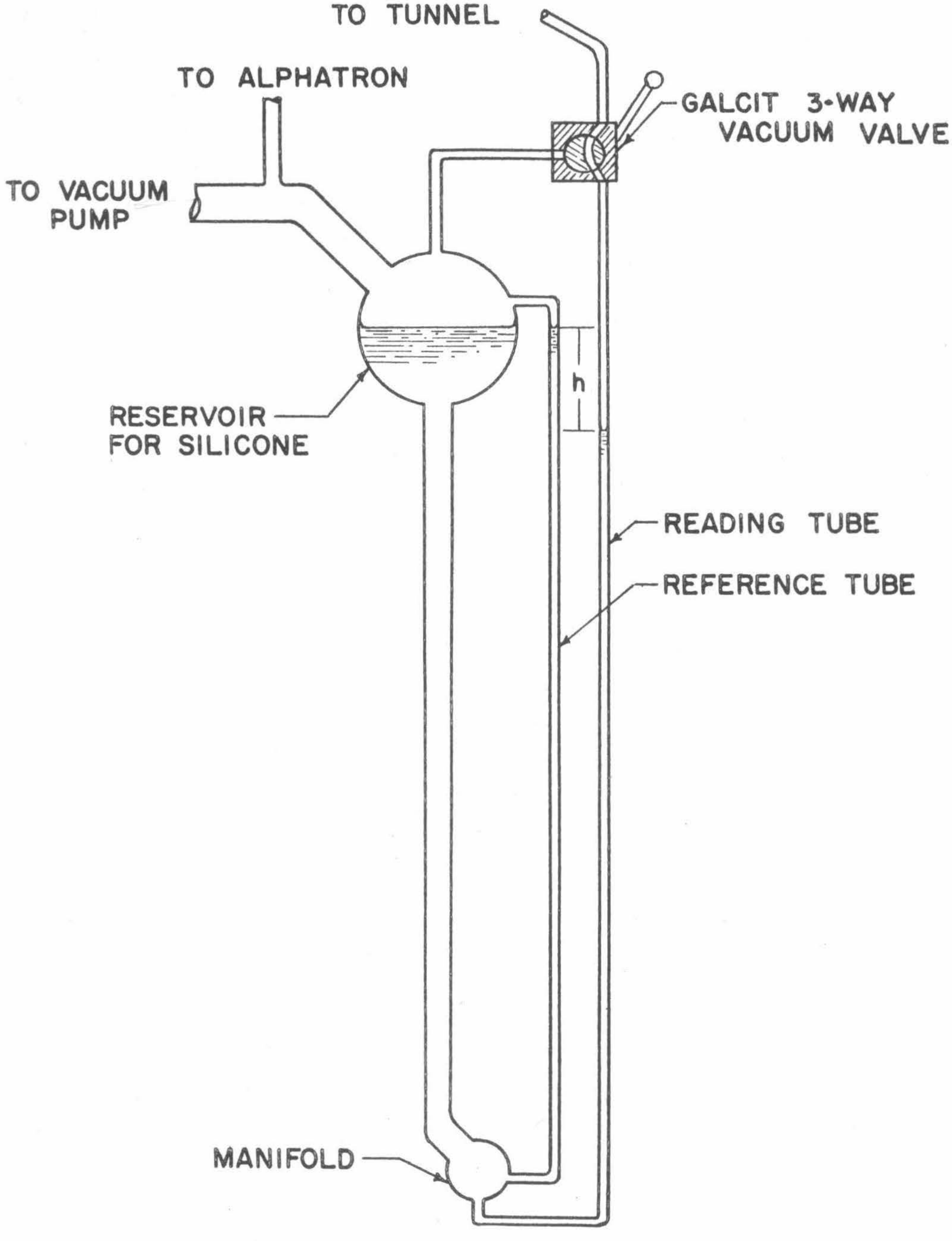
SCHEMATIC OF LEG NO. I TEMPERATURE CONTROL
FIG. 4

constant drop → constant air pressure



SCHEMATIC OF LEG NO. 2 HEATER CONTROL

FIG. 5



SCHEMATIC OF SILICONE MANOMETER
FIG. 6

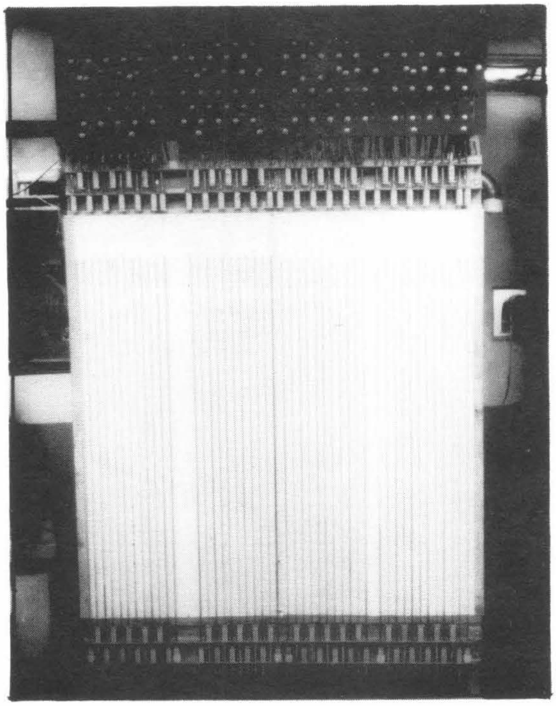


FIG. 7

MANOMETER BOARD

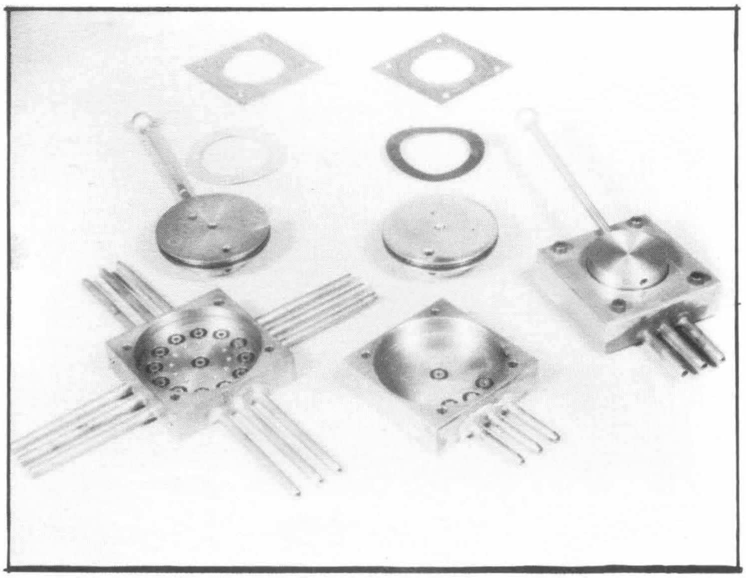


FIG. 8

LOW PRESSURE VALVES

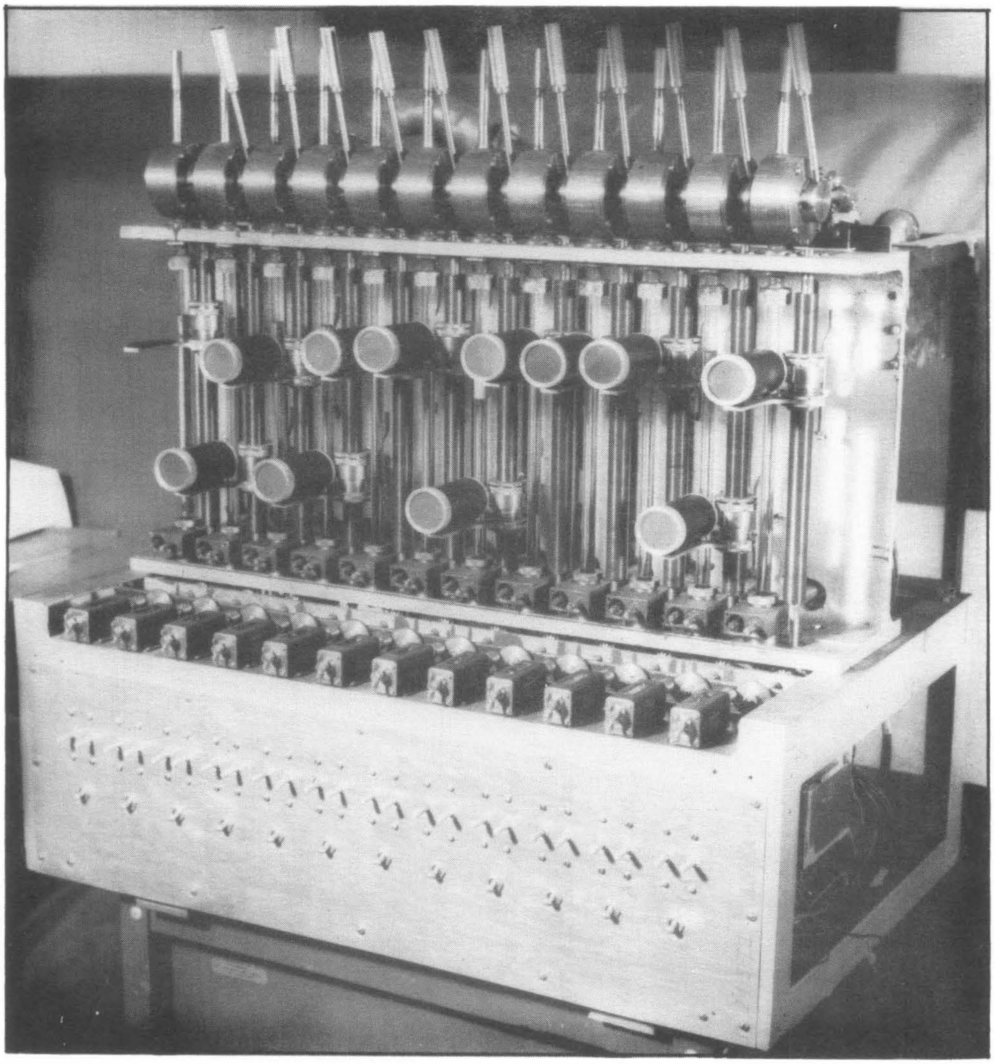
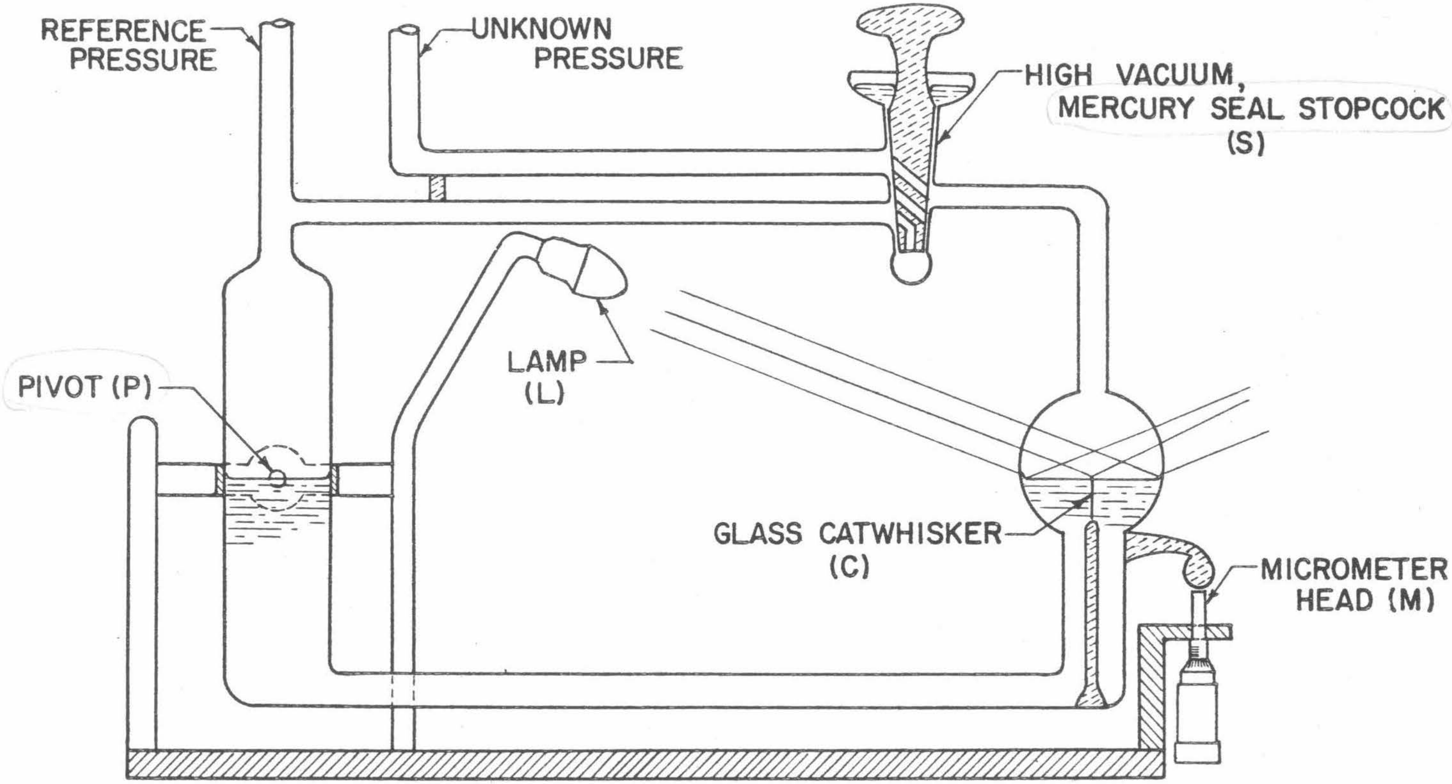


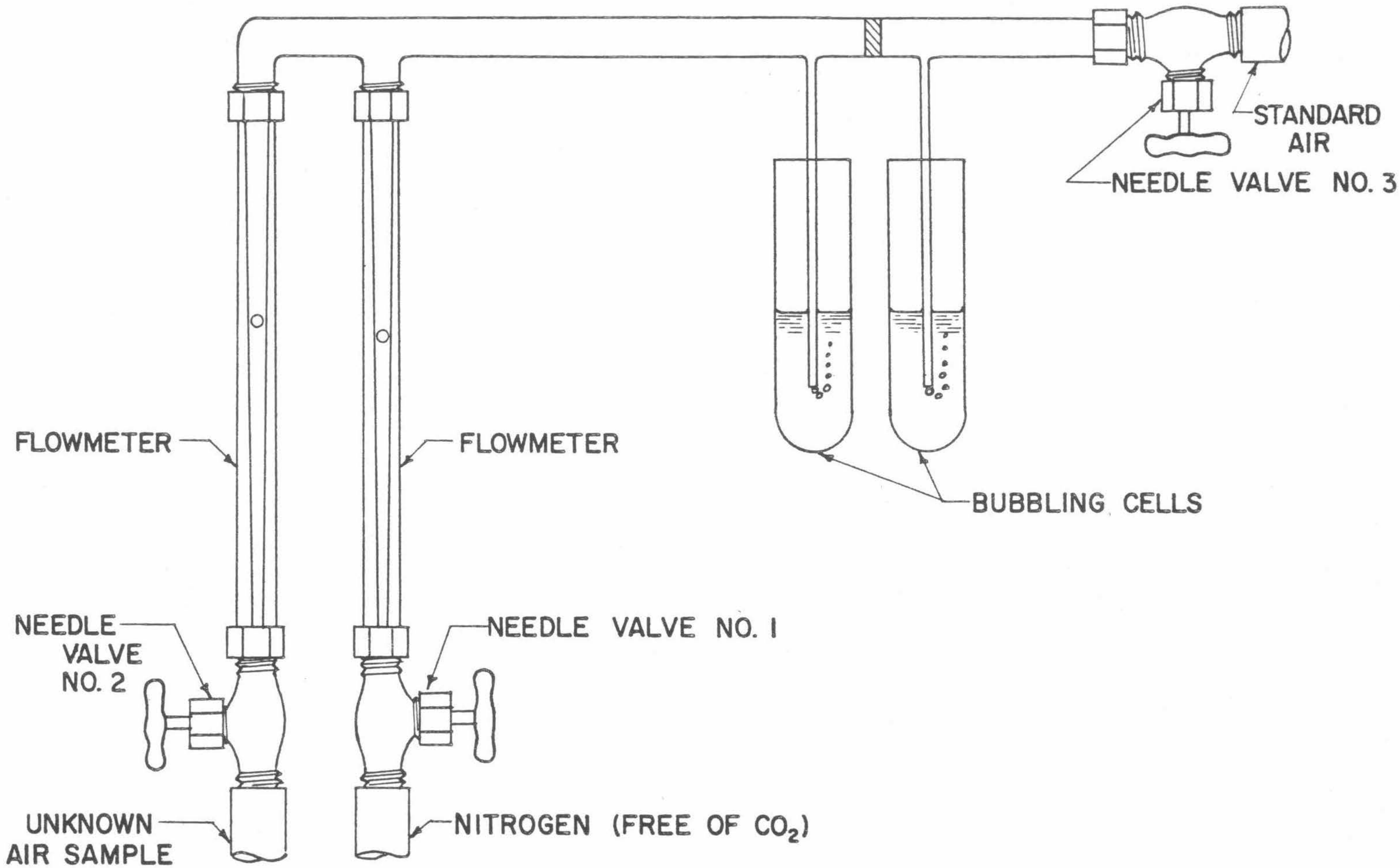
FIG. 9

12-TUBE MICROMANOMETER BANK



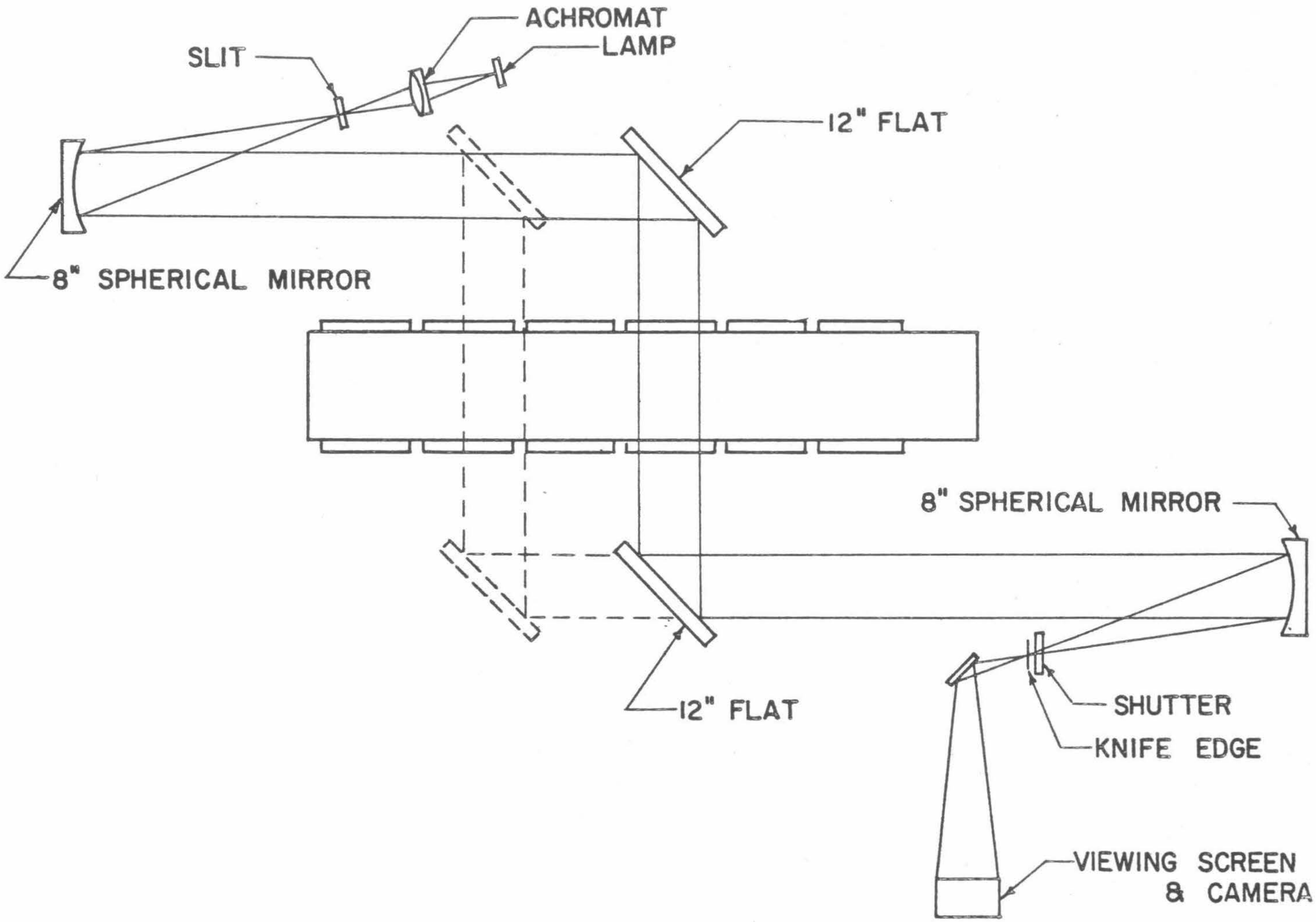
SCHEMATIC OF TILTING U-TUBE MICROMANOMETER

FIG. 10

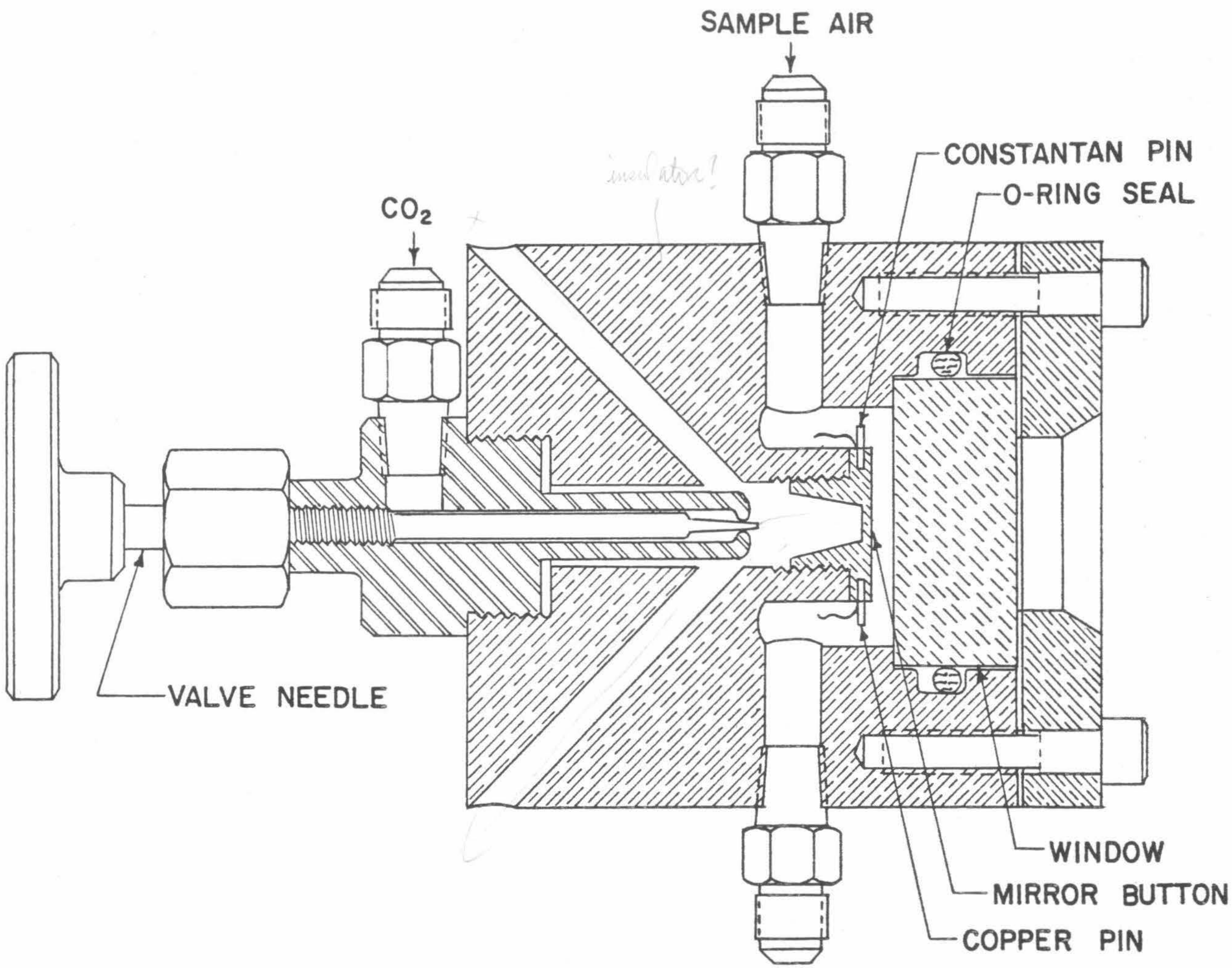


CARBON DIOXIDE CONCENTRATION METER

FIG. 11

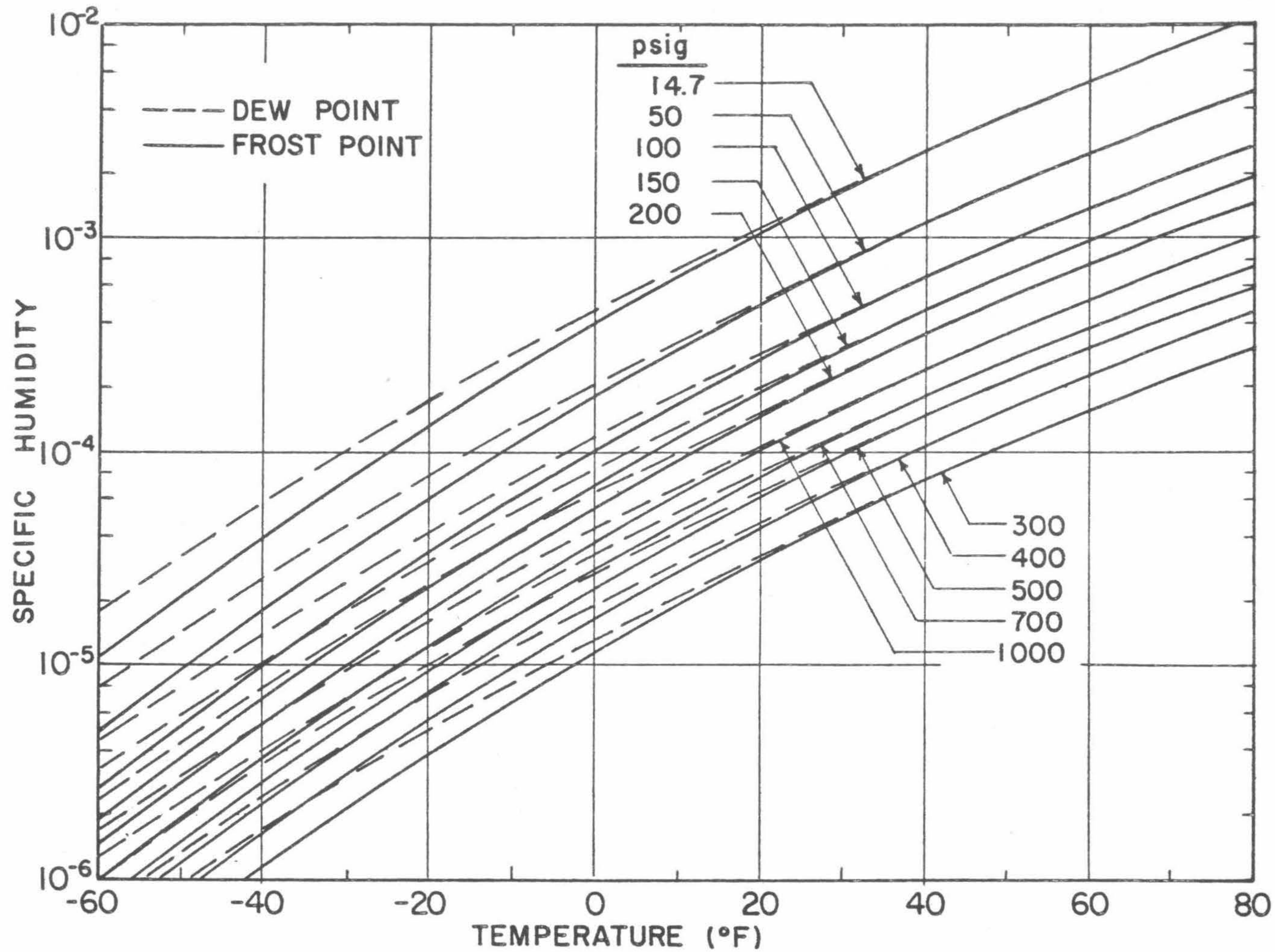


SCHEMATIC OF SCHLIEREN SYSTEM
FIG. 12



SCHEMATIC OF HIGH PRESSURE DEW POINT INDICATOR

FIG. 13



SPECIFIC HUMIDITY VS. DEW POINT TEMPERATURE
AT VARIOUS PRESSURE LEVELS
FIG. 14

CALIFORNIA INSTITUTE OF TECHNOLOGY
HYPERSONIC WIND TUNNEL
CONTRACT NO. DA-04-495-Ord-19

REPORT DISTRIBUTION LIST

Mr. E. L. Stone
Contracting and Purchasing Officer
Los Angeles Ordnance District
55 South Grand Avenue
Pasadena, California

Dr. Morton Alperin
Western Division
Office of Scientific Research
Hq., Air Research & Development Command
Post Office Box 2035
Pasadena 2, California

Mr. G. Stetson (2 Copies)
Office of the Chief of Ordnance
ORDTB - Ballistic Section
The Pentagon
Washington 25, D. C.

Office of Ordnance Research
Box CM, Duke Station
Durham, North Carolina

Chief of Ordnance (Memorandum & Tech. Reports Only)
Department of the Army
Washington 25, D. C.
ATTENTION: ORDTB
For Transmittal To
Department of Commerce
Office of Technical Information

Commanding General
Redstone Arsenal
Huntsville, Alabama
ATTENTION: Technical Library

Mr. C. L. Poor
Exterior Ballistic Laboratories
Aberdeen Proving Ground
Maryland

Mr. Joe Sternberg
Ballistic Research Laboratories
Aberdeen Proving Ground
Maryland

Commanding General
Headquarters
Air Research & Development Command
Post Office Box 1395
Baltimore 3, Maryland
ATTENTION: RDTRRF

Commanding General
Wright Air Development Center
Wright-Patterson Air Force Base
Ohio
ATTENTION: WCLSW

Commanding General
Wright Air Development Center
Wright-Patterson Air Force Base
Ohio
ATTENTION: Dr. Roscoe H. Mills (WCRRF)

Commanding General
Arnold Engineering Development Center
Tullahoma, Tennessee
ATTENTION: AEORL

Air Force Armament Center (ARDC)
Elgin Air Force Base, Florida
ATTENTION: Technical Library

Navy Department
Bureau of Ordnance
Technical Library
Washington 25, D. C.
ATTENTION: Ad-3

Commanding Officer
U. S. Naval Ordnance Laboratory
White Oak
Silver Spring 19, Maryland
ATTENTION: Library

Dr. R. K. Lobb
U. S. Naval Ordnance Laboratory
White Oak
Silver Spring 19, Maryland

U. S. Naval Inspector of Ordnance
Applied Physics Laboratory
Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland

Mr. Bernard F. Jaeger
Head, Aerodynamics Branch
U. S. Naval Ordnance Test Station
Inyokern
China Lake, California

Commander
Western Development Division
Post Office Box 262
Inglewood, California

Armed Services Technical Information Agency (5 Copies)
Document Service Center
Knott Building
Dayton 2, Ohio
ATTENTION: DSC-SD22

National Advisory Committee for Aeronautics
1512 H Street, Northwest
Washington 25, D. C.
ATTENTION: Aerodynamics Branch

Mr. John Stack
Associate Director of Research
National Advisory Committee for Aeronautics
Langley Memorial Aeronautical Laboratory
Langley Field, Virginia

Dr. John C. Evvard
National Advisory Committee for Aeronautics
Supersonic Propulsion Division
Lewis Flight Propulsion Laboratory
Cleveland, Ohio

Mr. H. Julian Allen
National Advisory Committee for Aeronautics
Ames Aeronautical Laboratory
Moffett Field, California

Library
Institute of the Aeronautical Sciences
2 East 64th Street
New York 21, N. Y.

ARO, Inc.
Post Office Box 162
Tullahoma, Tennessee

General Electric Company
Reports and Documents Division
2900 Campbell Avenue
Schenectady 5, New York

Ramo-Wooldridge Corporation
8820 Bellanca Avenue
Los Angeles 45, California

RAND Corporation
1700 Main Street
Santa Monica, California
ATTENTION: Miss Margaret Anderson, Librarian

Sverdrup and Parcel, Inc.
Syndicate Trust Building
St. Louis 1, Missouri

Mr. E. E. Clark
Chief of Aerodynamics
Glenn L. Martin Company
Baltimore 3, Maryland

Mr. A. Flax
Head, Aerodynamics Research Department
Cornell Aeronautical Laboratory, Inc.
4455 Genesse Street
Buffalo 21, New York

Mr. Martin Goland
Director for Engineering Sciences
Midwest Research Institute
4049 Pennsylvania
Kansas City 11, Missouri

Dr. Henry T. Nagamatsu
General Electric Company
Research Laboratory
Schenectady, New York

Dr. Allen E. Puckett
Hughes Aircraft Company
Culver City, California

Mr. E. Williams
RAND Corporation
Missile Aerodynamics Section
1700 Main Street
Santa Monica, California

Professor Harold O. Barthel
University of Illinois
Aeronautical Institute
Urbana, Illinois

Professor R. C. Binder
Purdue University
Lafayette, Indiana

Professor L. M. K. Boelter
University of California
Engineering Department
Los Angeles, California

Dr. Seymour M. Bogdonoff
Princeton University
Department of Aeronautical Engineering
Princeton, New Jersey

Professor Sin-I Cheng
Princeton University
Department of Aeronautical Engineering
Princeton, New Jersey

Professor Francis Clauser
Johns Hopkins University
Graduate School of Aeronautics
Baltimore, Maryland

Dr. R. Courant
New York University
New York, N. Y.

Professor H. W. Emmons
Harvard University
Department of Applied Physics
Cambridge 38, Massachusetts

Professor R. J. Emrich
Lehigh University
Department of Physics
Bethlehem, Pennsylvania

Professor Antonio Ferri
Polytechnic Institute of Brooklyn
Aerodynamics Laboratory
527 Atlantic Avenue
Freeport, New York

Dr. R. G. Folsom
Director, Engineering Research Institute
East Engineering Building
University of Michigan
Ann Arbor, Michigan

Dr. R. Paul Harrington
Rensselaer Polytechnic Institute
Aeronautics Department
Troy, New York

Dr. Rudolph Hermann
Department of Aeronautical Engineering
University of Minnesota
Minneapolis 14, Minnesota

Professor A. M. Kuethe
University of Michigan
Aeronautics Department
Ann Arbor, Michigan

Dr. Ting-Yi Li
Rensselaer Polytechnic Institute
Aeronautics Department
Troy, New York

Dr. C. C. Lin
Department of Mathematics
Massachusetts Institute of Technology
Cambridge, Massachusetts

Professor S. I. Pai
Institute of Fluid Dynamics and
Applied Mathematics
University of Maryland
College Park, Maryland

Dr. Ronald F. Probstein
Brown University
Division of Engineering
Providence, R. I.

Dr. S. A. Schaaf
Associate Professor of Eng. Sciences
Low Pressures Research, Inst. of Eng. Res.
Engineering Field Station
1301 South 46th Street
Richmond, California

Dr. W. R. Sears
Cornell University
Graduate School of Aero. Engineering
Ithaca, New York

Professor H. Guyford Stever
Massachusetts Institute of Technology
Aeronautical Engineering Department
Cambridge, Massachusetts

Professor R. G. Stoner
Pennsylvania State University
Physics Department
State College, Pennsylvania

Dr. M. J. Thompson
Defense Research Laboratory
University of Texas
Post Office Box 8029
Austin 12, Texas

Professor Gavin L. von Eschen
Ohio State University
Aeronautics Department
Columbus 12, Ohio

Dr. Th. von Kármán
1501 South Marengo Avenue
Pasadena 5, California

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena 2, California
ATTENTION: Reports Group

Dr. P. Wegener
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena 2, California

Dr. H. S. Tsien
Jet Propulsion Center
California Institute of Technology
Pasadena 4, California

Aeronautics Library
California Institute of Technology

Dr. Clark B. Millikan (2 Copies)
Dr. Julian D. Cole
Dr. Donald E. Coles
Dr. P. A. Lagerstrom
Professor Lester Lees
Dr. H. W. Liepmann
Dr. A. Roshko
California Institute of Technology

Hypersonic Design Group
Hypersonic Experimental Group
Hypersonic Theoretical Group
Hypersonic File
California Institute of Technology

TOTAL = 82